Towards a Parity Nonconservation Measurement in Stable Ytterbium Isotopes: the ac-Stark Effect

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Atomic parity nonconservation (PNC) experiments provide a valuable test of our understanding of both semi-leptonic and purely hadronic weak interactions. Parity-nonconserving weak interactions within the atom result in small modifications in the atom's optical properties. By observing these PNC-induced effects it is possible to make a low-energy quantitative test of the Standard Model of electroweak interactions and to study parity-nonconserving effects within the nucleus.

The $6s^2\,{}^1S_0 \rightarrow 6s5d\,{}^3D_1$ transition in atomic Yb is a promising system for the study of PNC [1]. In the absence of PNC effects, the electric-dipole (E1) transition amplitude is strictly forbidden by the parity selection rule, while the magnetic-dipole (M1) amplitude is highly suppressed. The application of an external electric field mixes even- and odd-parity states, giving rise to a Stark-induced amplitude ($\mathrm{E1_{St}}$). The weak interaction also mixes even- and odd-parity states, giving rise to a parity-nonconserving transition amplitude ($\mathrm{E1_{PNC}}$). In order to measure the very small $\mathrm{E1_{PNC}}$, one observes the interference between the much larger $\mathrm{E1_{St}}$ and $\mathrm{E1_{PNC}}$, as one excites this forbidden transition with intense laser light. The parity-nonconserving effect in Yb is expected to be very large, due to the presence of two energetically nearby states of opposite parity.

Comparing PNC effects in several stable isotopes of Yb will allow us to extract fundamental information about the weak interaction independent of atomic structure calculations. In addition, comparison of PNC effects in the different hyperfine components of the two isotopes of Yb that have non-zero nuclear spin will allow for a determination of the nuclear anapole moment, a key quantity in improving our understanding of hadronic PNC effects within the nucleus.

During the past year we have continued the development of the apparatus necessary for the PNC experiment. This work has included the successful implementation of a high-finesse ($\mathcal{F} = 6000$) optical power-build-up cavity. By increasing the number of resonant photons interacting with the atoms, the power-build-up cavity significantly improves the statistical sensitivity of the PNC experiment.

However, the intense optical standing wave that results from using a power-build-up cavity causes the resonance frequency of the atoms to shift due to the ac-Stark effect. Because atoms sample different parts of the optical standing wave they are shifted different amounts and the resulting spectral line shape becomes asymmetric at high powers (see Fig. 1). Understanding this shape and the size of the shifts is crucial for interpreting the PNC experiment. We have observed this effect experimentally and have developed a theoretical model to allow us to extract the ac-Stark shift parameters from the data.

In addition to the continued experimental work we have also pointed out that atomic Stark-interference experiments such as our future PNC experiment and our related M1 transition amplitude measurement [2] offer an opportunity to study exotic magnetoelectric effects such as Jones effects and directional anisotropy [3]. In fact, our measurement of the forbidden M1 amplitude [2] was the first reported observation of Jones dichroism.

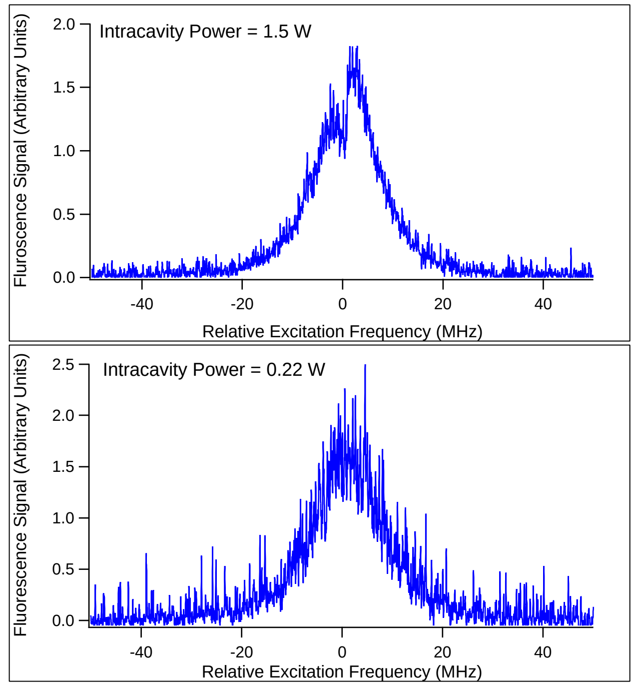

FIG. 1: Power-normalized fluorescence spectrum versus excitation frequency for two different powers. The scan shown in the top plot was taken at higher power and shows the asymmetry due to the ac-Stark effect. This feature is reduced in the scan taken at lower power (bottom plot).

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